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14. ABSTRACT

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Active underwater imaging, underwater detection, underwater identification, range gating

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In harbor underwater threat detection/identification using active imaging

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ABSTRACT

We present results from trials of the LUCIE 2 (Laser Underwater Camera Image Enhancer) conducted in Halifax Harbor, Nova Scotia, Canada and Esquimalt Harbor, Victoria, British Columbia, Canada. LUCIE 2 is a new compact laser range gated camera (10 inches in diameter, 24 inches in length, and neutrally buoyant in water) originally designed to improve search and recovery operations under eye safe restrictions. The flexibility and eye safety of this second generation LUCIE makes it a tool for improved hull searches and force protection operations when divers are in the water attempting to identify bottom lying objects. The camera is equipped with a full image geo-positioning system. To cover various environmental and targets size conditions, the gate-delay, gate width, polarization and viewing and illuminating angles can be varied as well. We present an analysis on the performance of the system in various water conditions using several target types and a comparison with diver and camera identification. Coincident in-situ optical properties of absorption and scattering were taken to help resolve the environmental information contained in the LUCIE image. Several new capabilities are currently being designed and tested., among them a differential polarization imaging system, a stabilized line of sight system with step-stare capability for high resolution mosaic area coverage, a precision dimensioning system and a diver guided and operated version.

Keywords: Active underwater imaging, underwater detection, underwater identification, range gating

1. INTRODUCTION

What makes the problem of in harbor underwater threat detection and identification such a difficult and frustrating task is the fact that ultimately identification must be carried out by visual means in waters that are generally turbid. These operations must be carried out both night and day and in shadowed and dark areas under ships and under docks. Therefore one cannot rely on having any kind of natural illumination. The necessity of using light sources that are co-located with the camera compounds the problem as a standard camera is often blinded by the backscattered light coming from the nearby scattering particles suspended in the water and lying between the target and the camera. Consequently to identify objects under these low visibility conditions divers or Remotely Operated Vehicles (ROVs) equipped with standard cameras and lighting systems must get very close to the target. Often divers and vehicles get so close that they disturb the silt and sediments lying over the target or on the bottom and create their own cloud of scattering particles. This additional turbidity can be quite large and the only practical solution is to stop all motion and wait for the current to advect the cloud from the target area. In the case of an ROV this basically means stopping the engines and lying on the bottom until the cloud dissipates. As subsurface inner harbor currents are often weak, this can result in waiting a minute or more in many cases. This increases the "time" required for the inspection of the target area.

A collateral and equally significant problem induced by the low visibility is the absence of knowledge and confusion about absolute position that can affect both divers and ROV operators. This can result in "holidays" in the coverage or inspection and implies the need for accurate underwater positioning or geo-referencing. In order to ensure complete coverage or inspection of an area, a dock or a ships hull, the positioning accuracy must be kept less than both the imaging range and the field of view (FOV) of the camera system. Sometimes potential targets have been detected and possibly classified by other sensors, sonar systems for instance. The small range of the camera can render the cross-sensor target handoff extremely difficult and time consuming. In order to operate efficiently in the in harbor underwater threat identification mission, electro-optics systems must maximize their range of operation and therefore must be designed to reduce, or if possible eliminate, the effects of turbidity. At the very least these systems should increase the

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identification range sufficiently to ensure that in high silt environments, divers or ROV systems do not create their own clouds.

There are three main benefits of this increased range. The first is a larger search swath, which leads to shorter operation times for a given required coverage. The second is a sufficiently high enough bottom or target clearance to carry out target identification in stride, i.e. without the obligation of frequently setting the ROV on the bottom. The last benefit is the ease of cross-sensor target handoff, including the assurance that both sensors did indeed look at the same target. In addition, even when the electro-optic system is carried by a ROV, divers must be used to prosecute whatever targets have been found. The system should therefore ideally be sufficiently eye safe to be operable in the presence of divers. Systems that use a combination of a short green laser pulse with a time gated image intensifier in order to enhance the range of visibility underwater occurred almost as soon as components were available. In such systems, a laser pulse is sent out and after a suitable delay the camera gate is turned on. This minimizes the intense backscatter from the water column lying between the target of interest and the camera from being recorded on the image since the camera's shutter is closed precisely during the time this radiance would enter the fore-optics.

In the course of the past few years, we developed such an underwater range gated active imaging system (Laser Camera Image Enhancer LUCIE) originally for the express purposes of visually identifying bottom-laying mines and helping in underwater search and recovery operations. The system was found to have a range of three to five times the range of a standard camera and this range increase was experimentally shown to be in many cases sufficient to allow on the fly target identification with a ROV. The system uses a high repetition rate diode pumped doubled Neodymium Vanadate green laser with seven nanoseconds pulse widths. The high repetition rate means that the applicable eye safety conditions depend on average power density considerations and not on the single pulse total energy density criterion. The average eye safe power level is therefore higher by a factor of approximately one thousand, when compared with for example a 10 Hz flash lamp pumped doubled YAG laser. The system is eye safe at 50 cm in its wide illumination (800 milliradians) beam configuration and 2 meters in its narrow (200 milliradians) illumination beam configuration. If total eye safety is required, a simple factor of 10 notch filter could be incorporated in the diver mask. This still allows sufficient "through the mask transmission" in the blue and green to not hinder normal diver vision. The LUCIE system therefore satisfies both of our criteria for an effective in harbor electro-optic detection system.

2. EVOLUTION OF THE LUCIE SYSTEM

The LUCIE underwater range-gated imaging system has evolved through two very different generations. The first system[1] used a compact high efficiency laser diode pumped Nd-YAG doubled into the green by crystals of either BBO or KTP. Two versions of this first generation system underwent a series of trials in various environments ranging from harbor to open ocean. Both versions were mounted on a Remotely Operated Vehicle (ROV) and tested using long dwell times required for reliability testing, on a bottom-resting platform with pan and tilt capability. During all the various trials, simultaneous measurements were taken of water column the absorption and scattering coefficients along with the near forward scattering phase function. These measurements were carried out using a near forward nephelometer and transmissometer (NEARSCAT). These simultaneous measurements[2] allowed us to both model and extrapolate performance data to waters with different properties.

Both versions of the camera proved to be extremely reliable. In cases were there was no or little natural illumination, and one had to rely on onboard lighting systems, the range gated system allowed one to extend the useful imaging range from a factor of three to five when compared to a normal camera with 500 watt quartz-iodine lamps. We found that in many circumstances, typical survey and identification missions could be carried out approximately 10 times faster than with standard imaging equipment. Part of this speed increase was due to the larger coverage due to the extended range. Another significant contributor to the efficiency of survey was the capability of the ROV to hover and image at a sufficient distance from sandy or muddy bottoms that its own motors did not raise significant amounts of scattering material in the water column. We did not foresee this highly nonlinear effect on identification mission effectiveness before the trial results were analyzed.

Our original versions of LUCIE were built to allow a great deal of experimental flexibility and were fitted on a large ROV (Hysub 5000 from ISL). They were contained in a set of 3 joined cylinders 30 cm in diameter and 1 meter long. The system weighed 300 kilos and required 750 watts of inrush power and 500 watts of continuous power. This large

size made the system difficult and expensive to operate. We therefore decided to investigate the feasibility to miniaturize the system without significant sacrifice to system performance, thus increasing the ease of operation and the overall utility to other mission areas.

One of the success stories of early trials was the extraordinary reliability of the high repetition rate diode pumped doubled Neodymium laser. In several instances the first camera was immersed and operated underwater for several days. After being in storage for over a year, the camera was also brought back to full functionality and readiness in less than 24 hours. The delay was due to a small leak that had developed in a seal of the liquid cooling system of the laser. The second important successful part of the original design was the inherent eye safety of the high repetition rate diode pumped lasers. Because of the high repetition rate, the eye damage threshold for the pulsed laser becomes identical to the CW damage limit. This much higher wattage figure means that even in clear waters the system is eye-safe at a maximum distance of 1.5 meters from the aperture. This allowed divers to operate around the camera while it was in operation. [This alone improved the evaluation of the systems search rate capabilities relative to those of divers]. We therefore keep this approach in our second-generation system. We decided, however, to use an air and conduction cooled laser to both alleviate weight and ensure against potential system leaks. Consequently our new camera is a completely dry system, a feature which considerably enhances its long term reliability. The high repetition rate also implies that the in-water speckle is averaged out over each frame. This in itself is a significant benefit if we wish to apply modern image enhancement techniques to the results. As stated above, the camera uses an air cooled Neodymium Vanadate laser with a KTP doubling crystal. The doubled output at 532 nm is 1.50 watt average in water at a repetition rate of 22 kHz with a pulse length of 5 ns. The average power is, however, sensitive to the diode temperature. A reduction of 3 degrees centigrade from a nominal set point of 27 degrees will reduce the power by 50%. This then required that the overall system temperature needs to be stabilized by a sensitive controller driving an array of Peltier coolers/heaters placed underneath the laser enclosure.

The most desirable improvements that were identified from an analysis of our original results were:

- Smaller size, weight and power
- Flat-field initial laser illumination matched to camera FOV
- Predictable illumination degradation
- Fixed beehive pattern removal (removal of minifier)
- Higher resolution
- Larger FOV
- Programmable AGC
- Optimized signal processing (Poisson noise dominance)
- Improved user interface

In our second-generation camera, the size has been reduced from the heavy 3 cylinders to one cylinder 25X70 cm in length and weighting 45 kilos. The power consumption has also been reduced by more than a factor of 3 to an average 175 watts. The illumination system is controlled by a holographic beam shaper that produces a flat illumination field with a 4/3 aspect ratio. This aspect ratio matches the field of view (FOV) of a standard video camera. The intensity varies by less than 5% over 90% of the FOV. Given an initial intensity distribution of this type it is relatively easy to compute its transition to a Gaussian shape illumination as the beam propagates through natural waters with their typical forward peaked scattering phase functions. The spatial degradation of the illuminating field is predictable at all zoom settings and ranges[3-4]. This allows numerical intensity compensation algorithms to be applied in the new design.

One extremely annoying feature of intensified cameras is the appearance of a beehive pattern superimposed on the image. This beehive pattern is due to the varying transmission through the fiber bundles (minifiers) used to collect the light output of the phosphor on the back plate of the image intensifier and reduce it to a size appropriate to the CCD array of the video camera. In order to eliminate this effect our camera now uses a high aperture (f=0.8) lens to image the phosphor directly on the CCD. The light collection efficiency is reduced by a factor of two but this is irrelevant since we use a gated tube in chevron configuration with a luminous gain of 1,000,000 that can count individual photons if required. It can still count photons even with the reduced efficiency of the lens over the fiber bundle. We have found that the image is more pleasing to the operator and much easier to apply image enhancement algorithms too.

Another improvement is that a slightly higher resolution is obtained by using a 25mm diameter photo-cathode intensifier tube rather than the usual 18 mm type. The photo-cathode has a low noise (500 counts s^{-1} cm^{-2}) T type S20 coating with a 10% quantum efficiency at 532 nm. We have found that our new camera is able to easily resolve 200 line pairs across the width of the screen. The lens system is now 10 cm in diameter with a zoom range of 16 mm to 160 mm at an f=1.8. The lens has an auto-iris control and fully motorized focus and zoom. Both camera and illuminator can be zoomed from 80 to 800 mr in water. The laser divergence and zoom lens system can be slaved together to ensure maximum uniform illumination over the entire range of field of views. This larger field of view is achieved at the same sensitivity level as in our first generation system because of the larger diameter photo-cathode. The intensifier gate delay can be varied from 0 to 500 ns and the gate width can be increased from 3 ns to 500 ns. Diagrams and a laboratory photograph of this new system are shown in the next three figures. Figure 1 is a schematic front view of this new system. Figure 2 is a side view of the same LUCIE2 system showing a block diagram of the components. Figure 3 is a picture of the actual camera system.

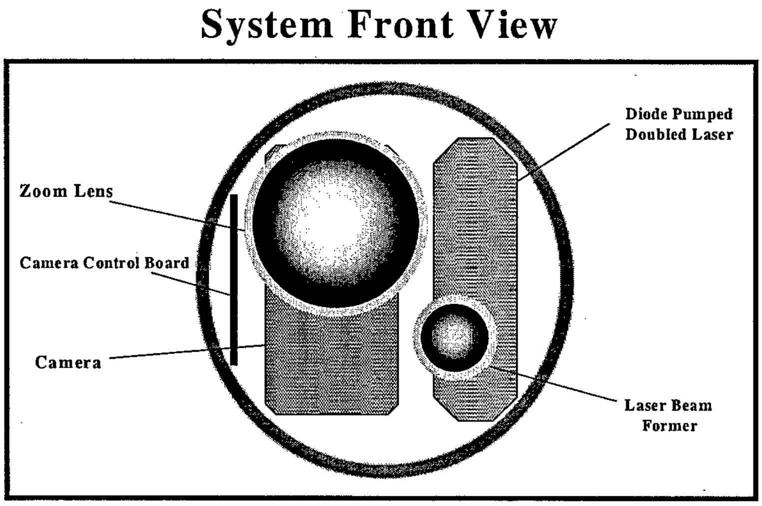

Figure 1. Schematic of the front view of the LUCIE2 range gated imager. The zoom lens is 10 cm in diameter and the laser beam exit port is 2.5 cm in diameter. The ports are separate to avoid back scattering of the laser beam in the receiving optics.

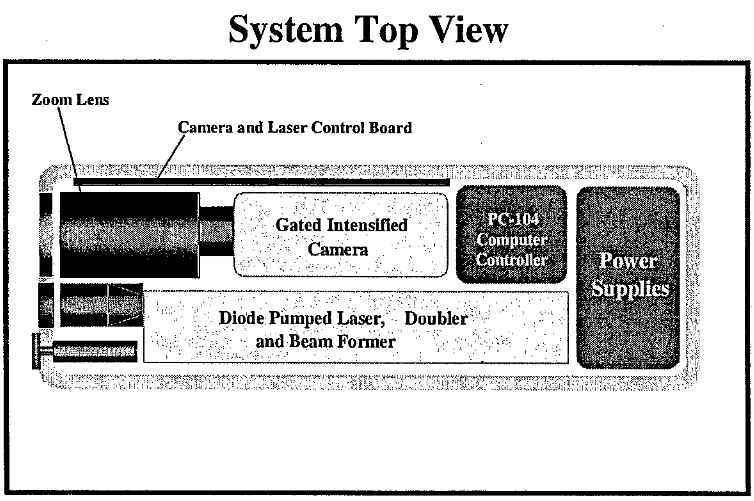

Figure 2. Schematic of the top view of the LUCIE2 range gated imager showing a block diagram of the components.

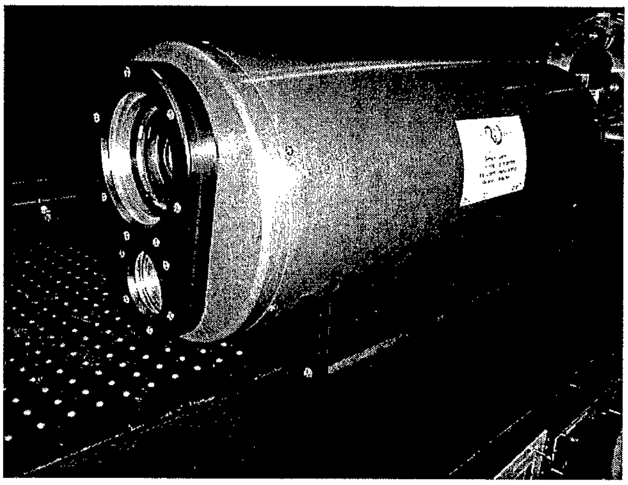

Figure 3. Picture of the LUCIE2 camera. The system is 25 cm in diameter by 70 cm in length. The receiving optics are 10 cm in diameter.

The video output is digitized by a frame grabber at full resolution 640 pixels by 480 pixels at 30 frames per second. This allows application of a substantial amount of real time processing to the camera such as frame averaging, smoothing by convolution, histogram equalization, contrast stretching, sharpening filters and other enhancement techniques. This approach also allows testing of several automatic gain control (AGC) algorithms that operate over the full range of gain of the camera i.e. from photon counting mode to full illumination.

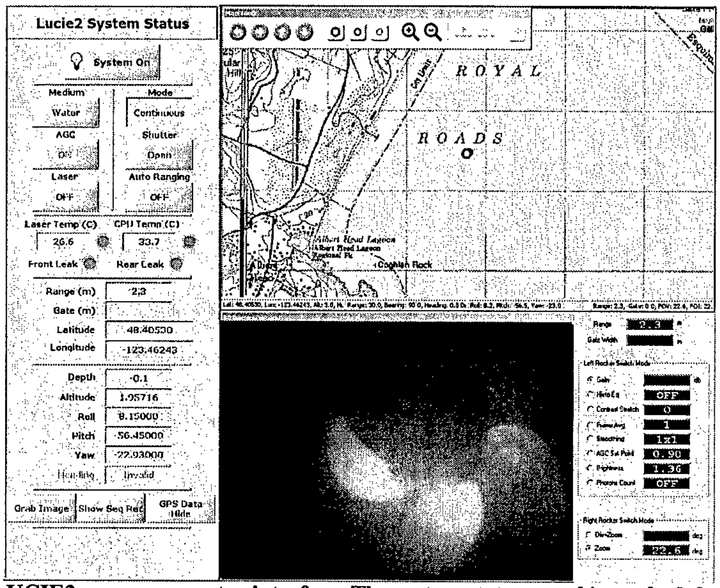

Figure 4. Picture of the LUCIE2 camera operator interface. The system status panel is on the left. The range-gated image is presented in the bottom center frame. The image processing functions are controlled from the bottom right menu and the geo-location functions are displayed and controlled from the top right frame.

With this numerical approach we have developed a fairly sophisticated user interface where virtually all of the controls for the camera operation, orientation and choice of image processing methods are situated on one joystick control; the remainder of the functions are accessible by a touch screen. Consequently the system is user friendly and operator training time can be kept to a minimum. Figure 4 is a picture of the operator console. As mentioned in the caption, the

system status and control panel is on the left. The range-gated image as enhanced by real time image processing is presented in the bottom center frame. The image processing functions are controlled from the bottom right menu and all compatible processing functions can be turned on simultaneously by the operator. The geo-location functions are displayed and controlled from the top right frame. These functions allow one to navigate over the map, to mark targets, and to view the swath covered so far by the imaging system. In the particular case shown, the ship and ROV and camera were operating in Esquimalt Harbor just outside of Victoria on the island of Vancouver.

Because of its relatively small size, the camera can be operated either from a small cradle directly attached to a boat in shallow waters, or mounted on a ROV for deeper water operations. In the trials in Halifax in February 2002, the cradle was extensively used. In the trial in Esquimalt Harbor in March 2004, both the cradle and a ROV were used. Figure 5 shows LUCIE mounted on a Deep Ocean Engineering Phantom class ROV during the Esquimalt trials. As shown LUCIE2 is encased in a custom tailored envelope made of standard wet suit material. This envelope helps to reduce the power expenditure necessary to control the internal temperature of the system. As mentioned above, this control is required to ensure that the laser and frequency doubling system function at peak efficiency.

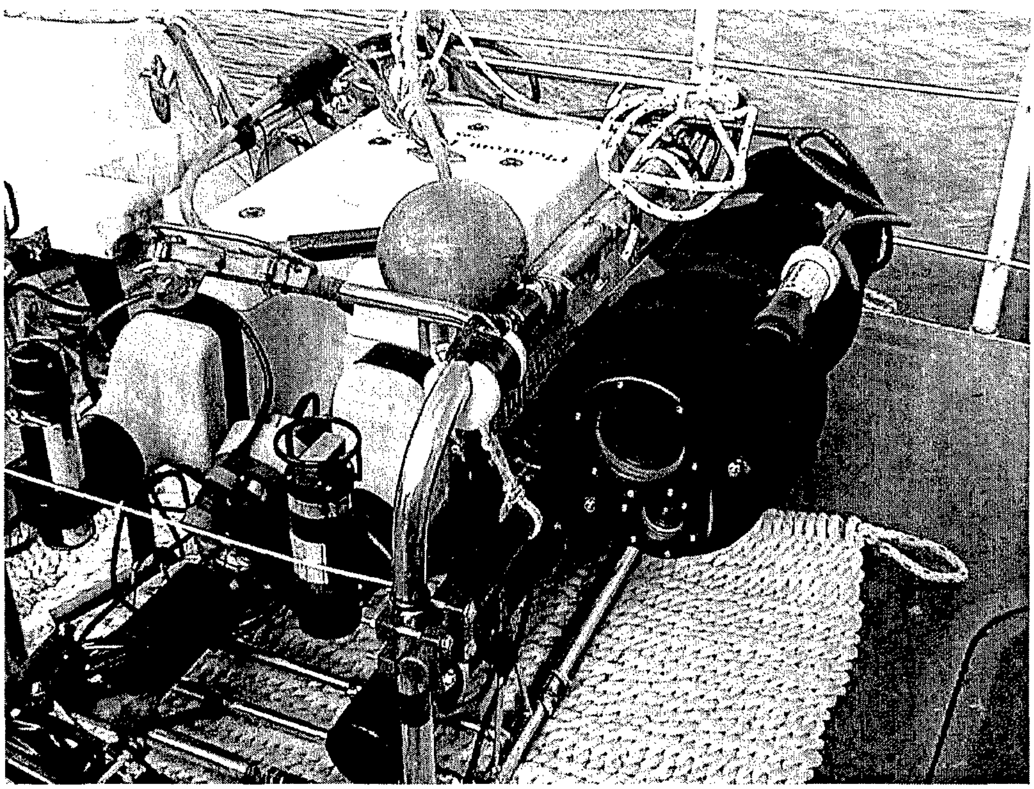

Figure 5. Picture of the LUCIE2 camera mounted on the side of a Deep Ocean Engineering Phantom ROV. LUCIE2 is encased in a custom tailored enclosure made of standard wet suit material.

3. IN SITU OPTICAL MEASUREMENTS

In trials of the previous system we carried out simultaneous measurements of the relevant optical properties of the waters in which we were operating. This data, when combined with simple models, gives insight into the potential system performance in varied coastal and harbor conditions. The measurements included absorption and attenuation at nine wavelengths (WetLabs Inc., ac-9 plus), backscattering at 140 degrees, and radiance attenuation (HobiLabs Inc., a-beta at 532 nm), scattering at 100, 125 and 150 degrees (Wetlabs ECOVSF), and CTD. Figure 6 shows a typical example of the vertical profile of both absorption and extinction coefficients measured in the inner harbor in Halifax 100 meters away from the untreated exhaust from a main sewer pipe. In this case the water temperature was 1^0C.

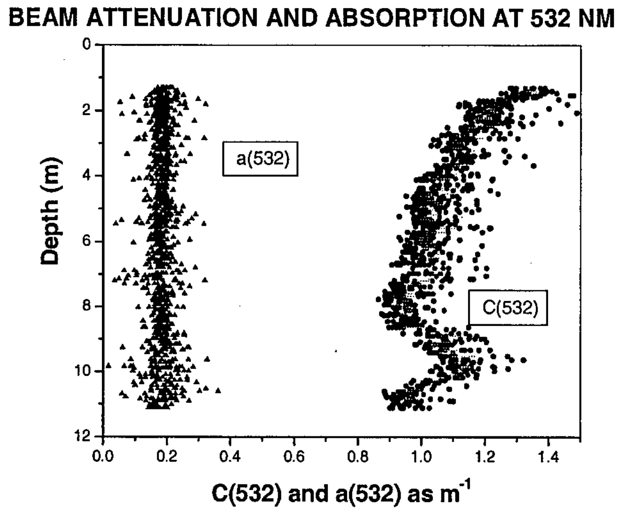

Fig. 6. Depth profile of absorption and beam attenuation at 532 nm showing increase from 0.9 to 1.2 m^{-1} near the bottom for c (532).

In the Halifax trials the work was carried from a small boat moored to a main pier. The optical properties as a function of depth changed with the tidal cycle, sewage discharge, and wind direction. Scattering layers were found at both the surface and at depth depending on the tidal cycle, wind, and discharge. The measurements of the optical properties of the water column are generally of good quality. In some cases the presence of large quantities of big particles (centimeter size and larger) was evident. Since these particles can substantially or completely block the optical paths of the instruments, their effects on absorption, scattering and the phase function, are not properly accounted for by the instrumentation used or there "in-frequency" in a statistical sense means that they are "seldom measured." In the case of the very particular waters we were operating in, the results are therefore a lower limit on the values of these parameters. We have not yet found a reliable method to properly compensate this effect.

The same measurements were carried out in the Esquimalt trials of March 2003 but we did not encounter the same problem since the trials were carried out in this case either from a ROV or directly from the rear deck of the HMCS Whitehorse, a Canadian coastal patrol vessel whose primary mission is to carry out detailed side scan sonar surveys of the harbor and its approaches. In this case we were well removed from any sewage outlet. Note that the simultaneous measurement of the total scattering coefficient at several wavelengths allows one to approximate the near forward angle behavior of the phase function and to determine the precise inverse power dependence of the particle size distribution. With this information, it is then possible by using a few large angle scattering measurements at one wavelength to fit the complete experimental data by a phase function model [5]-[6]. This model depends only on the inverse power as a function of size of the particle size distribution and on the average relative index of refraction of the particles. The current sets of measurements are thus sufficient for us to ultimately determine to a satisfactory accuracy all the relevant

parameters necessary to build a complete theoretical model of the experiment. This model will be a considerable help in the further analysis and generalization of our trial results.

4. THE HALIFAX TRIALS AND RESULTS

The first trials were carried out between February 13 2002 and February 21 2002 along side pier 9 in Halifax harbor. As previously mentioned, the test site was located less than a hundred yards from a main untreated sewer outlet, a situation that created a serious challenge to the imaging system. The water depth at the test site was 10 meters and the level of natural light at the bottom was high. The LUCIE2 underwater enclosure was first mounted on a large pan and tilt mount that could rest on the bottom and was hydraulically powered. A small aperture large depth of field Fischers diver camera with two 150 watts quartz-iodine lamps was attached to the mount. This camera provided both the standard source of illumination for normal camera use, and served as a second reference for performance comparison. The first reference is the camera in LUCIE2 itself, which can be used in un-gated mode as a standard high sensitivity video camera.

Several sets of targets were used during the trial. The first set of diver visibility targets used was a set developed by W. Mcbride and T. Bowers of Planning Systems Incorporated. These consisted of calibrated sets of black line pairs on a white background. The line widths ranged from 1 mm to 128 mm on two different panels. The line spacing in millimeters, which is double the line width, is indicated on the side of each line pair set. At different times during the trial we also used other target types. We used a line set (white lines on black background), which had served in all our previous experiments. The line widths range from 1.5 mm to 48 mm. Each subsequent line pair set is the double in size of the previous set. Following the procedures we had established during our previous trials using the first generation imager, the various targets were imaged at several different ranges under as many different environmental conditions as possible. Coincident measurements of the optical properties of the water column were carried out.

Because water depth was shallow (10 m) and background illumination high, we had the opportunity to measure the performance of the camera against that of divers during this field test. To carry out the comparison, we used the black line against white background targets. A measuring tape was attached to the target and the divers moved back from the target noting at what distance they stopped distinguishing between the discrete line pairs in a target set, and when the set itself was indistinguishable.

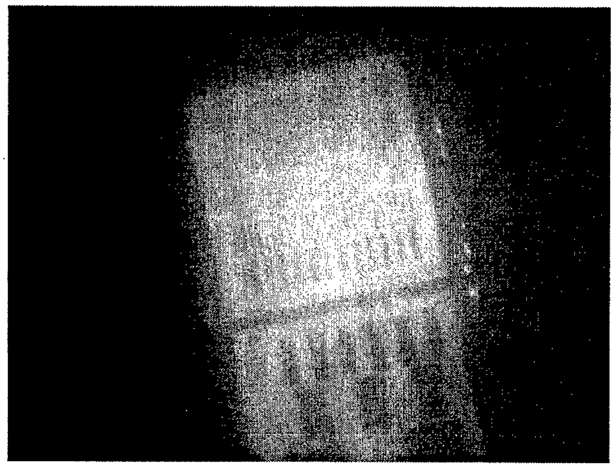

Figure 7. Picture taken by LUCIE2 at a range of 5 meters under conditions in which divers reported a visibility of 3 meters. The diagonal field of view is 20°. Note that the 16mm lines are clearly distinguishable (4th row from the top).

The environmental conditions were particularly challenging on the day this test was carried out. The measured absorption coefficient was 0.2 m^{-1} and the scattering coefficient was 0.8 to 1.0 m^{-1}. On that day we were in the middle of a sewer plume discharge and a nearby ship's bilge was adding significantly to the turbidity. In these particularly

difficult conditions, the divers reported a visibility range of approximately 3 meters (10 feet). Beyond this range they could still distinguish the presence of a white diffuse target but they could not make out any details whatsoever.

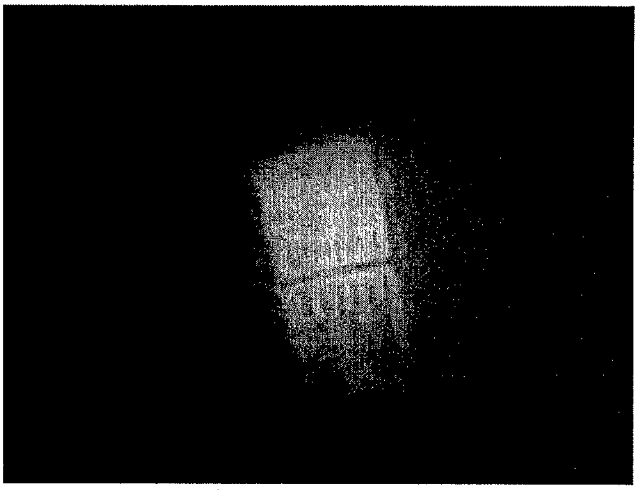

Figure 8. Picture taken by LUCIE2 at a range of 5 meters, with diver visibility noted to be 3 meters, but with a diagonal field of view of 40°. The lines on the bottom row (32mm lines), on the top panel, are distinguishable.

Figures 7 and 8 are the images taken by LUCIE2 under the same conditions at a distance of 5 meters from the same target. Figure 7 is a narrow field of view picture (20° along the diagonal) while figure 8 is a wider field of view under the same conditions (40° along the diagonal). In the first picture the 16 mm spacing line pairs are easily distinguishable while the 8 mm spacing are a blur. In the second picture it is the 32 mm spacing that is the smallest visible. This behavior is as expected from the combination of the camera modulation transfer function and the excess blur due to in-water scattering. We estimate from this data that in these harbor environmental conditions the LUCIE2 system range is about twice that of divers. Abundant natural sunlight is the ideal condition for normal viewing systems (human vision or a standard video camera). At night or in deep shadows were a diver would have to carry lights, the increase in range from the use of a range gated camera in similar conditions will go back up to a factor of 3 to 5.

5. THE ESQUIMALT TRIALS AND RESULTS

The second set of trials were carried out between March 11 2003 and March 17 2003 either directly from the rear deck of HMCS Whitehorse or from a phantom class ROV. As in Halifax the first deployment site was alongside the pier in the inner harbor. The second site was located in directly the harbor approaches. When operating directly from the ship, a small winch was used to lower and raise a simple cradle holding the camera. The mean water temperature in this case was 5^0C. In this case no interference from sewage was present. The same targets and procedures were used as in Halifax. The water conditions were somewhat clearer than Halifax with beam attenuation at 532 nm at about 0.55 to 0.8 m^{-1} and absorption at about 0.1 m^{-1} for the key test areas.

For the duration of the Esquimalt trials, LUCIE2 was operated in a polarized mode. The laser was left-circularly polarized and the analyzer was similarly left-circularly polarized. The reflection from a smooth surface returns in a circular polarization state of the opposite sign to that of the incoming wave. Using an analyzer of the same polarization state has the first advantage of considerable reducing the backscatter from air bubbles and larger transparent spherical and spheroidal suspended particulates. This phenomenon reduces some sources of backscatter and can therefore increase the target visibility range in cases were large transparent scattering particles are dominant in the water column. The second advantage is subtler and occurs when one is trying to image metallic surface or painted surfaces with scratches down to the bare metal. By using this polarization setup, the reflected return light from the metal surfaces are either completely cancelled or substantially reduced. This property lowers the glint to a tolerable level where much finer details and contrast differences can be detected. To illustrate this, figure 9 is a range-gated image of the propeller of the

HMCS Whitehorse that had just been refurbished and scraped clean. In un-polarized light, the range-gated camera would be blinded by the glint coming back from elements of the surface.

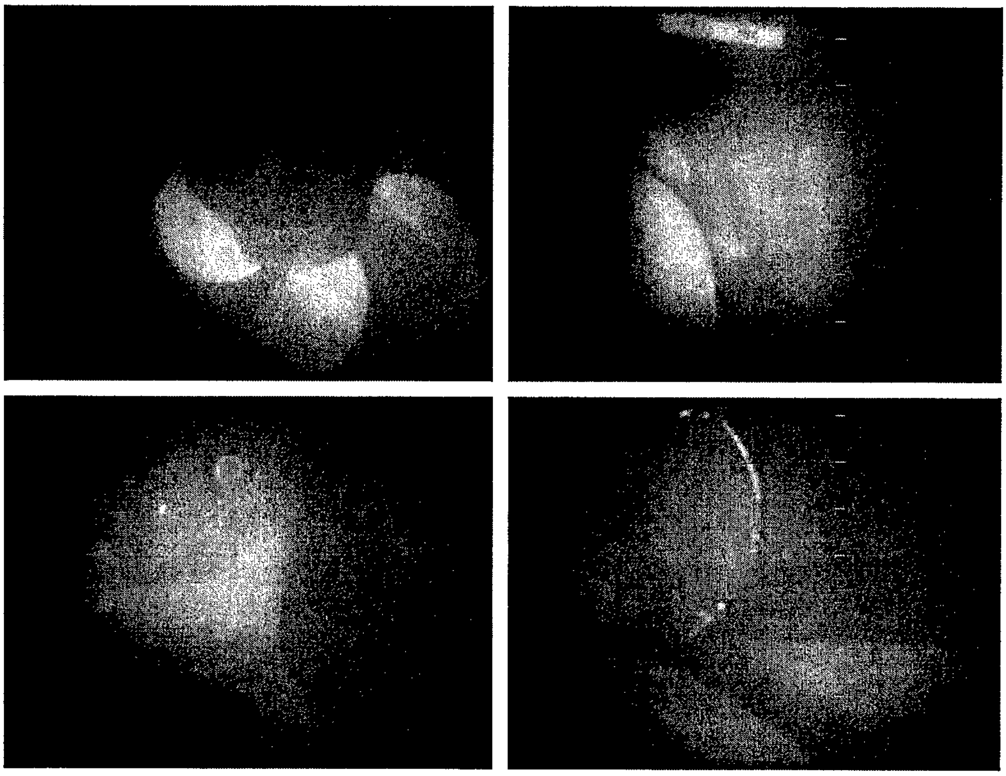

Figure 9 is a set of pictures of the root of a propeller taken from a distance of over 5 meters with a narrow 200 mr diagonal field of view with changing "zoom" condition. The laser and analyzer were both left circularly polarized. Note the detail in the imaged "bolts" and the wear in the "propeller blades".

This is obviously not the case for as can be seen in figure 9 were some fairly subtle contrast changes can be observed. Figure 9 is a series of images showing a close-up of the root of a propeller taken from a distance of over 5 meters with a narrow 200 mr diagonal field of view. The figures demonstrate the added value of the variable zoom and the ability to automatically gate a distance. If we were not using circularly polarized light with an analyzer of the same handedness the highlights would actually completely saturate the picture. Even using polarized light, when compared with the cameras of the phantom ROV, we found that the range advantage of LUCIE2 over a conventional camera was again a factor of 3 to 5 times, substantially the same performance as during all our previous trials. The series shows bolts and blade wear even at a distance of 5 meters in water with a beam attenuation of nearly one inverse meter.

6. FUTURE WORK

The task of accurately and completely surveying both the bottom hull under a ship and the surface of the ship while in port is far from trivial. After studying the results of our previous in-harbor trials, we came to the conclusions that several system improvements would be extremely desirable and proceeded to initiate work on them.

The first improvement is the capability of electronically changing the laser polarization state and the polarization state of the analyzer used in front of the gated camera in real time, i.e. frame to frame if possible. To this end we have designed and are building such a new polarization control optical system that we plan to add to the LUCIE camera shortly. The reason such a system is highly desirable is that in many circumstances polarization difference techniques allow one to improve the potential target contrast particularly when it is partially hidden by underwater vegetation. Figures 10 and 11 are an example of what can be achieved by some simple processing. They were kindly given to us by

Y. Rasmussen et al[7]. They show a piece of iron from a shell that was left underwater for many years and a fresh piece of polished aluminum both partially hidden by vegetation. In figure 10, both pieces of metal are barely distinguishable. Using normalized linear polarization differencing, the target to background contrast is significantly increased as can be seen in figure 11.

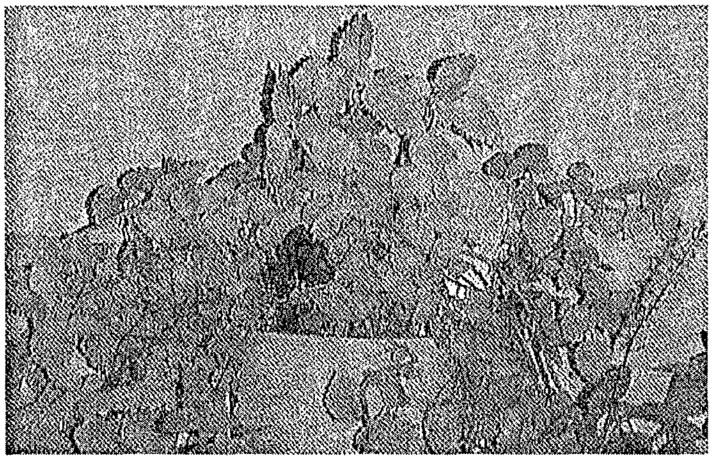

Figure 10. Picture taken in un-polarized laser light of a piece of rusted iron(on the left) and a piece of freshly polished aluminum (on the right) partially hidden by vegetation.

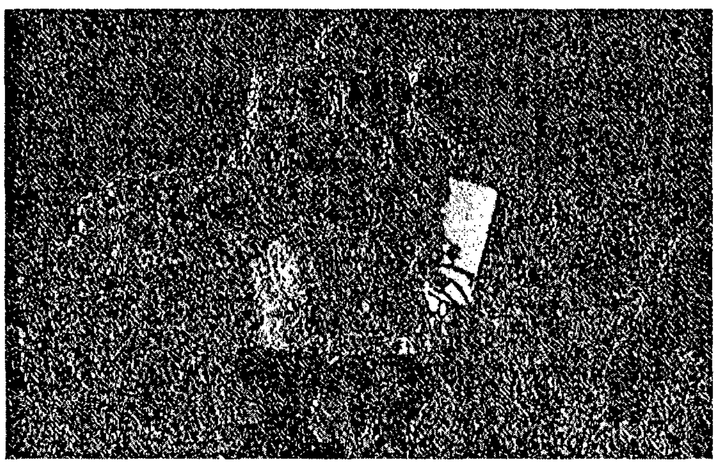

Figure 11. Normalized linear polarization difference picture of a piece of rusted iron and a piece of freshly polished aluminum partially hidden by vegetation. Notice the significant target to background contrast enhancement.

The second most significant improvement is the capability to produce detailed real-time mosaic or waterfall displays of the bottom, pier structures, and ship surface. In order to carry out this process efficiently, we have found it necessary to improve the camera system in several ways. We first added via software a precise image dimensioning capability so that the operator immediately knows the scale of the object he is viewing. We are also further reducing the LUCIE2 device size and we are adding a pan and tilt mirror system to control the line of sight over 180^0 vertical and 120^0 horizontal. This compact device will allow the camera to be operated and used effectively on modest size ROVs. As an added bonus, the mirror system will be used to stabilize the line of sight (LOS). This means that one can conveniently zoom in to an area of interest with out having to set the ROV on the bottom. In low light cases this also gives an enhanced capability to integrate the image over long time periods to reduce the photon noise and improve the picture clarity. The

LOS stabilization can also operate in a step-stare mode that allows one to image large areas by creating a mosaic of pictures taken at high zoom magnification and therefore high resolution. Finally, we are adding a fiber optical capability to handle the substantially increased data throughput anticipated for operational use. We should note that this new system is commercially available from the D-FENSE Inc. company in Quebec City[8].

The advancements in the LUCIE system and its operational success on ROVs and in comparisons with diver testing suggest that this system has potential for use in harbor inspection of vessels and piers. The new automated system allows for a rapid survey capability. The 'zoom' and polarization enhancements allow the user to quickly locate an object against its background; mark the position; and then zoom in to examine the details of the object. The LUCIE system offers a system for routine or spot examination of key harbor structures. Its operation in waters of poor visibility but with good area coverage rates suggests it should be considered an asset for in-water harbor security.

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